

**APPARATUS AND METHOD FOR  
REDUCING PROPAGATION DELAY IN A CONDUCTOR**

TECHNICAL FIELD

The present invention relates to electrical and integrated circuits and, in particular, to an electrical conductor for an electrical and/or integrated circuit.

BACKGROUND

The transmission speed of an electrical signal along a conductor medium in an electrical circuit (including an integrated circuit and/or semiconductor device) is dependent on several factors. For a pulse transmitted through a conductor medium having a given length and wave velocity, the propagation delay of the pulse depends on the length of the medium and the wave velocity. The wave velocity, in turn, is related to the dielectric constant of the surrounding medium and the speed of light.

Another factor that delays the signal is caused by the resistance and capacitance of the conductor medium, commonly called the RC time constant. The speed of an electrical signal decreases when capacitance increases. Similarly, speed increases when capacitance decreases. The capacitance of the conductor medium depends on several factors, mainly the environment surrounding the conductor medium.

Accordingly, there exists a need for an apparatus and method for reducing the effective capacitance in a conductor of an electrical circuit thereby increasing the speed of an electrical signal transmitted along the conductor. Further, there is needed a conductor with relatively low capacitance for increasing the speed of an electrical signal transmitted therealong. Additionally, there is needed a method of constructing a conductor in an electrical circuit that reduces the capacitive effects surrounding the conductor and increases the speed of an electrical signal transmitted on the conductor.

SUMMARY OF THE INVENTION

According to the present invention, there is provided an apparatus for decreasing the propagation delay time of an electrical signal transmitted along a conductor in a circuit. The apparatus includes a first conductor having a length extending from a first area of the circuit to a second area of the circuit and for carrying the electrical signal.  
5 A second conductor located proximate the first conductor extends substantially parallel and along the first conductor, with the second conductor electrically coupled to the first conductor.

In another embodiment of the present invention, there is provided a conductor for transmitting a clocking signal from a first area to a second area of an integrated circuit.  
10 The conductor has a first elongated conductive portion extending from the first area to the second area and a second elongated conductive portion located proximate and spaced apart from the first conductive portion and extending substantially parallel with the first conductive portion. The conductor also includes a third elongated conductive portion  
15 located proximate and spaced apart from the first conductive portion and extending substantially parallel with the first conductive portion. The first conductive portion is electrically connected to the second conductive portion and the third conductive portion.

In yet another embodiment of the present invention, there is provided a method of forming an electrical conductor in a circuit that increases the speed of an electrical  
20 signal transmitted along the conductor. The method includes the steps of fabricating a first conductor having a length extending from a first area of the circuit to a second area of the circuit, and fabricating a second conductor proximate the first conductor and

extending substantially parallel and along the first conductor, the second conductor electrically coupled to the first conductor.

5 The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized  
10 by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is made to the following description taken in conjunction with the accompanying drawings, wherein:

5           FIGURE 1 is cross-sectional view of a semiconductor (or printed circuit board) substrate illustrating the capacitance between three signal lines (i.e., conductors) in the substrate;

FIGURE 2 is a diagram illustrating a conductor in accordance with the present invention;

10 *sub 3*           FIGURE 3A is a more detailed diagram and top view of the conductor set forth in FIGURE 3;

*sub 1*           FIGURE 3B is a cross-sectional view along line A-A of FIGURE 3A;

*sub 2*           FIGURES 4A-4C illustrate different configurations or embodiments of the conductor in accordance with the present invention;

15           FIGURES 5A-5C illustrate cross sectional views of different embodiments of the conductor of the present invention;

FIGURE 6A is a graph illustrating the improvement in rise time (i.e. showing propagation delays) of a signal on a conductor in accordance with the present invention; and

20           FIGURES 6B-6D illustrate each of the configurations for the signal waveforms shown in FIGURE 6A.

DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawings, like reference characters designate like or similar elements throughout the drawings.

Now referring to FIGURE 1, there is shown a cross-sectional view of a medium  
5 (semiconductor integrated circuit or printed circuit board, or the like) 8 having a substrate layer 20, an insulation layer 10, a first conductor 12 (also referenced as conductor A), a conductor 14 (also referenced as conductor D) and a conductor 16 (also referenced as conductor E) formed in the insulation layer 10. As will be appreciated, if the medium  
8 is printed circuit board, the substrate layer 20 may not be present. FIGURE 1 also  
10 shows capacitance paths 18 (illustrated in dotted lines) between the first conductor 12 and the conductors 14, 16. Additionally shown in FIGURE 1 are the substrate layer 20 (which may include a conductive layer or other elements) and capacitance paths between the conductor 12 and the substrate layer 20. In addition, capacitance paths may exist between the conductor 12 and other elements or materials located proximate (above, beside, below) the conductor 12, but are not shown for convenience.  
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As will be appreciated, as the conductor 12 extends through the medium 8, many different conductors or elements having different (and dynamic) electrical signals thereon will be positioned proximate the conductor 12. These couple capacitively to the conductor 12. It is readily understood that the amount of capacitive coupling depends on  
20 several factors, including the distance from the conductor 12, the length of the coupling region, the rate of change of the potential difference between conductor 12 and each proximate conductor, and the dielectric constant(s) of the material(s) therebetween. The

total value of the capacitance is one factor that determines the "speed" and/or propagation delay of an electrical signal transmitted along the conductor 12. As the capacitance increases, the speed decreases (or propagation delay increases). Therefore, reducing the capacitance that an electrical signal "sees" as it propagates along the conductor 12 will  
5 increase its speed (or decrease its propagation delay).

In general terms, a signal on one conductor increasing in voltage while a signal on another conductor decreases in voltage (resulting in an increase in delta over time) generates the maximum capacitive effect, while two signals increasing (or decreasing) together generates the least capacitive effect. In other words, the capacitive effect is great  
10 between non-shielded conductor lines when both signals are active and opposite in direction. This effect remains substantial when one signal is active (increasing or decreasing) and the other signal is static (e.g., one signal is rising to a logic one and the other signal is held at a logic zero).

Now referring to FIGURE 2, there is illustrated a circuit 100 having a conductor  
15 120 extending from a first circuit 112 located in a first area 114 of an integrated circuit 100 to a second circuit 116 located in a second area 118 of the integrated circuit 100. The conductor 120 has a length L, as shown in FIGURE 2. The conductor 120 in accordance with the present invention reduces or decreases the propagation delay time (increases the speed) of an electrical signal transmitted along the conductor 120. As will  
20 be appreciated, the circuit 100 may also be any other electrical circuit, including a printed circuit board. Accordingly, the description of the present invention with respect to integrated circuits is also applicable to printed circuit boards and the like. In the

preferred embodiment, the signal transmitted on the conductor 120 is a clocking signal and the propagation delay of the signal is reduced or decreased, thus increasing the speed of the signal.

To obtain most of the benefits and advantages of the present invention, the length  
5 L of the conductor 120 should be more than about 250 microns, and preferably about 1000 microns or more. As will be appreciated, when used in an integrated circuit, the length L will most likely be less than 50,000 microns, depending on the size of the integrated circuit substrate. The signal(s) transmitted on the conductor 120 are generally about 10 MHz or greater and, preferably, about 200 MHz or greater, to obtain the many  
10 advantages of the present invention.

Now referring to FIGURE 3A, there is illustrated a more detailed diagram of the conductor 120 of the present invention. The conductor 120 includes a first conductor 120a, a second conductor (or conductive portion) 120b extending substantially parallel and along the first conductor 120a, and a third conductor (or conductive portion) 120c  
15 extending substantially parallel and along the first conductor 120a. The conductors 120a, 120b, 120c are shown extending from the first circuit 112 (in the first area 114) to the second circuit 116 (in the second area 118) (see also FIGURE 2). Each of the conductors 120a, 120b, 120c are made of any conductive metal or material, preferably of low resistance, including copper, tungsten, aluminum, polysilicon or other material, or  
20 combination thereof.

It will be understood that due to routing and process constraints and requirements, the additional conductor(s) may not run along the conductor 120a the entire distance L,



but instead substantial portions may run along the conductor 120a.

Now referring to FIGURE 3B, there is shown a cross-sectional view cut along line A-A of FIGURE 3A. The conductors 120a, 120b, 120c are formed in a insulating layer 200 (of an integrated circuit or printed circuit board, or the like). Additional layers of substrate may be provided, such as a substrate layer 202. The conductors 120b and 120c are each spaced apart substantially laterally from the conductor 120a, with the conductor 120b positioned along one side of the conductor 120a and the conductor 120c positioned along the other side of the conductor 120a. As will be appreciated, using present processes and methods, the width of each of the conductors is generally about 0.7 microns and the spacing therebetween is about 0.7 microns. However, the width and spacing dimensions may vary, and elements/dimensions in the figure may vary and may not be drawn to scale. It is expected that next generation processes will generate widths on the order of 0.2 to 0.4 microns, and perhaps even smaller.

Now referring to FIGURES 4A-4C, there are illustrated different configurations or embodiments for electrically connecting the conductors 120b, 120c to the main conductor 120a. In FIGURE 4A, the conductors 120a, 120b, 120c are electrically connected at or near the source end, as illustrated, using a conductive material, such as the material used to fabricate the conductors. It will be understood that the designations "source" and "destination" are used for convenience and illustrative purposes only, and that the designations could be switched, such that the source end may refer to the first circuit 112 or first area 114, or the second circuit 116 or second area 118. Moreover, the conductor 120 (or 120a) may be bi-directional, depending on the desired circuitry and

functioning of the integrated circuit (or electrical circuit).

Now referring to FIGURE 4B, there is illustrated another configuration or embodiment of the conductor 120 wherein the conductor 120a is electrically connected at one end to three separate drivers 210. Each driver 210 drives the respective conductors 120a, 120b, 120c. The drivers 210 may include any other type of circuitry, and are not limited to inverters.

Now referring to FIGURE 4C, there is illustrated yet another configuration or embodiment of the conductor 120 wherein a plurality of switches 220 are used to electrically connect the conductor 120a to the conductor 120b, and to electrically connect the conductor 120a to the conductor 120c. The switches could also be tri-state devices. It will be understood to those skilled in the art that other circuits and methods may be used to electrically connect the conductor 120a to the conductors 120b, 120c.

As shown in FIGURE 4C, the conductors 120b and 120c could also be utilized by other circuitry when the conductor 120a is not active, unused, or when a signal is transmitted whose speed or propagation delay is unimportant. This is accomplished using switches and/or tri-state devices with appropriate control lines, and can be implemented by those skilled in the art.

Now referring to FIGURES 5A-5B, there are shown cross-sectional views of several embodiments of the conductor 120 alternative to the embodiment shown in FIGURES 3A and 3B. In FIGURE 5A, the conductor 120 includes a first conductor 120a, a second conductor (or conductive portion) 120b extending substantially parallel and along the first conductor 120a, and a third conductor (or conductive portion) 120c

extending substantially parallel and along the first conductor 120a. The conductors 120b and 120c are each spaced apart substantially vertically from the conductor 120a, with the conductor 120b positioned along the top side of the conductor 120a and the conductor 120c positioned along the bottom side of the conductor 120a.

5           Now referring to FIGURE 5B, there is shown another alternative embodiment of the present invention that includes the features illustrated in FIGURES 3B and 5A. The conductor 120 includes a first conductor 120a and a plurality of conductors (or conductive portions) 120b, 120c, 120d, 120e, whereby the conductors 120b, 120c, 120d, 120e each extend substantially parallel and along the first conductor 120a. The conductors 120b and  
10       120c are each spaced apart substantially laterally from the conductor 120a, with the conductor 120b positioned along one side of the conductor 120a and the conductor 120c positioned along the other side of the conductor 120a. The conductors 120d and 120e are each spaced apart substantially vertically from the conductor 120a, with the conductor 120d positioned along the top side of the conductor 120a and the conductor 120e  
15       positioned along the bottom side of the conductor 120a.

          Now referring to FIGURE 5C, there is shown yet another alternative embodiment of the present invention. The conductor 120 in includes the conductors 120b, 120c, 120d, 120e as set forth in FIGURE 5B, and also includes a conductor 120f, a conductor 120g, a conductor 120h, and a conductor 120i, as shown in FIGURE 5C.

20           Now referring to FIGURES 6A-6D, there are shown in FIGURE 6A signal waveforms in graphical representation illustrating rise times for a prior art conductor shown in FIGURE 6B, for one embodiment of the present invention shown in FIGURE

6C, and for another embodiment of the present invention shown in FIGURE 6D.

In FIGURE 6B, there is shown the prior art conductor 12 with additional conductors 14 and 16. The width of each conductor 12, 14, 16 is about 0.7 microns and the spacing therebetween is about 2.1 microns. The conductors 14 and 16 are not electrically connected to the conductors 14 and 16.

In FIGURE 6C, there is shown one embodiment of the present invention having the conductor 120 including the conductor 120a and 120b. The width of each conductor 120a, 120b, 14, 16 is about 0.7 microns and the spacing between the conductors 14, 120b and 120a is about 0.7 microns while the spacing between the conductors 120a and 16 is about 2.1 microns. The conductors 120a and 120b are electrically connected while the conductors 14 and 16 are not electrically connected to the conductor 120.

In FIGURE 6D, there is shown one embodiment of the present invention having the conductor 120 including the conductor 120a and 120b. The width of each conductor 120a, 120b, 120c, 14, 16 is about 0.7 microns and the spacing therebetween is about 0.7 microns. The conductors 120a and 120b are electrically connected while the conductors 14 and 16 are not electrically connected to the conductor 120.

Now referring to FIGURE 6A, there is shown a graph of voltage (volts) versus time (nanoseconds) comparing simulation results of the present invention with a prior art conductor. An ideal signal waveform for a signal transition from a logic zero (about 0 volts) to a logic one (about 3.3 volts) is identified by reference numeral 600, and illustrated with an instantaneous rise time. For the prior art conductor illustrated in FIGURE 6B, the waveform of a signal on the conductor 12 is identified by reference

numeral 602, with the conductors 14 and 16 held at a logic zero. As is shown, the prior art conductor 12 has a rise time (measured at about 90% of the logic one level of about 3.3 volts) of approximately 0.28 nanoseconds due to the capacitive effects of the conductors 14 and 16 on the conductor 12.

5           Now referring to two of the embodiments of the present invention as illustrated in FIGURES 6C and 6D, there is a substantial decrease in the rise time and corresponding decrease in the propagation delay (or increase in speed) for the conductor 120 of the present invention. As will be appreciated, the conductor 120a corresponds to the prior art conductor 12 shown in FIGURE 6B. For the conductor 120 (including the conductors  
10   120a and 120b) illustrated in FIGURE 6C, the waveform of the signal on the conductor 120a is identified by reference numeral 604, with the conductors 14 and 16 held at a logic zero. As is shown, the conductor 120a has a rise time of approximately 0.16 nanoseconds due to the capacitive effects of the conductors 14 and 16 on the conductor 12. By adding the additional conductor 120b substantially parallel and along the conductor 120a, the  
15   conductor 120a is "shielded" from some of the capacitive effects of the conductors 14 and 16 on the conductor 120a. The conductor 120 results in an increase in speed and decrease in rise time (with a corresponding decrease in propagation delay) of a signal transmitted on the conductor 120.

          For the conductor 120 (including the conductors 120a, 120b and 120c) illustrated  
20   in FIGURE 6D, the waveform of the signal on the conductor 120a is identified by reference numeral 606, with the conductors 14 and 16 held at a logic zero. As is shown, the conductor 120a has a rise time of approximately 0.13 nanoseconds due to the

capacitive effects of the conductors 14 and 16 on the conductor 12. By adding the additional conductors 120b and 120c substantially parallel and along the conductor 120a, the conductor 120a is "shielded" from some of the capacitive effects of the conductors 14 and 16 on the conductor 120a. The conductor 120 results in an increase in speed and decrease in rise time (with a corresponding decrease in propagation delay) of a signal transmitted on the conductor 120. The decrease/gain in rise time is about 0.15 nanoseconds. As shown, the decrease in rise time (increase in speed) is greater than a factor of two (and the corresponding reduction in propagation delay is greater than 50%).

As will be appreciated, the signal on the conductors 120b and 120c will have slower rise time in voltage at the end of the conductor line than the conductor 120a. It will also be understood that the advantages of the present invention are also present for decreases in voltage (fall time) and not limited to increases in voltage (rise time).

The capacitive effect (which causes delay) becomes greater as the dimensions of the integrated circuit (including printed circuit boards) decreases, and the next smaller generation of integrated circuits will incur a greater capacitive effect from line to line. Therefore, the present invention will be of increased benefit for future generation devices.

Although the present invention and its advantages have been described in the foregoing detailed description and illustrated in the accompanying drawings, it will be understood by those skilled in the art that the invention is not limited to the embodiment(s) disclosed but is capable of numerous rearrangements, substitutions and modifications without departing from the spirit and scope of the invention as defined by the appended claims.